Successful Implementation of Multi-Stage Gas Emissions Reductions at 1050 MWₑ Coleson Cove Generating Station Using Reburn, WFGD and WESP Technologies

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Abstract

New Brunswick Power (NB Power) is the largest electric utility in Atlantic Canada with a generating capacity of more than 4000 MW, consisting of nuclear, thermal, and hydro. Among the generation portfolio, Coleson Cove generating station with its 1050 MW$_e$ generating capacity is NB Power’s largest generation facility. In 2002, NB Power embarked on a multi-facet emissions reduction and plant improvement program:

1. to reduce nitrogen oxides (NO$_x$) emissions level by at least 70% to achieve 0.21 lb NO$_x$/10$^6$ Btu or better by utilizing low NO$_x$ burners with air staging and reburning technologies;
2. to reduce sulfur dioxide (SO$_2$) emissions by installing a 90% efficient wet limestone desulphurization (WFGD);
3. to reduce below the visible threshold sulfur trioxide (SO$_3$) acid mists by utilizing a wet electrostatic precipitator (WESP) integral to the WFGD tower;
4. to reduce dry particulate emissions by 75% using WESP congruent with the existing dry electrostatic precipitators; and
5. to improve overall plant efficiency by renovating steam turbines with new HP/IP inner casings and rotors, complete with modern blading.

This paper outlines NB Power’s emissions reduction planning strategy for the Coleson Cove generating station. It also describes the design and performance characteristics of the combustion system with oil reburning plus the WFGD and WESP systems retrofitted at Coleson Cove generating station. Design features and performance achieved are included.

Introduction

The Coleson Cove generating station (Figure 1), consisting of 3x350 MW$_e$ units, is located on the Bay of Fundy. The units are dispatched mostly as load following units when system demand exceeds the combined capacity generated by nuclear, hydro, and coal-fired units.

The boilers were originally designed to burn heavy oil and are typical 1970s vintage design. Each unit was equipped with high turbulence burners in a compact furnace, having high heat release per plan area in the order of 2.58 10$^6$ Btu/ hr ft$^2$ (at 350 MW$_e$ load). When operated on heavy oil, this combustion system produced NO$_x$ emissions typically in the range of 1.0 to 1.2 lb/10$^6$ Btu. In addition, due to high burner zone heat release, the lower furnace historically suffered from chronic slagging that led to excessive reheater spray, causing a reduction of overall plant efficiency. Depending on the sulfur content in the fuel, approximately 3.1 lbs SO$_2$ was produced on average per million Btu heat input basis.

In 2002, NB Power began a refurbishment and emissions reduction program at Coleson Cove to renovate the steam...
turbines and boilers with a goal to improve overall plant operating and emissions performance. For NOx reduction, both in-furnace and post-combustion flue gas cleaning with selective catalytic reduction (SCR) options were considered. To reduce SO2 emissions, wet flue gas desulphurization was considered with the ability to produce gypsum suitable for wallboard manufacturing. In addition, a wet electrostatic precipitator was deemed the most suitable technology for elimination of SO3 acid mists. Improving overall plant efficiency and minimizing additional station service loads were recognized as an important factor to reduce fuel cost as well as directly contribute to lower overall emissions. The steam turbines were retrofitted with new HP/IP inner casings and rotors, complete with modern blading technology for best efficiency. Boiler pressure parts were strategically modified to reduce superheater and reheater sprays.

In-furnace NOx reduction

When the boilers at Coleson Cove were planned in the early 1970s, a compact, cost effective design was implemented. The combustion systems maximized heat input per boiler unit volume with a small furnace and rapid mixing burners. Consequently, NOx emissions were high by today’s standards. Considering the mechanism of NOx formation, the most effective means of reducing NOx during combustion is to reduce oxygen and combustion temperature. Staged combustion with low NOx burners and overfire air (OFA) ports were obvious considerations for the project. However, with NB Power’s ambitious goal of reducing NOx by greater than 70%, more advanced NOx control technologies, such as reburning and flue gas recirculation to the burners, would be required.

Reburning technology was introduced in the 1980s for NOx control in coal-fired boilers. Full scale experience with reburning technique for oil-fired boilers occurred mostly in Italy where oil was the dominant fuel for thermal power generation. The Italian utility ENEL has successfully applied reburning methods to achieve greater than 80% NOx reduction (Pasini 2000). This helped provide confidence to NB Power that its NOx reduction goal was achievable. Furthermore, combustion with reburning also limited the amount of furnace water wall that was exposed to the risk of fire-side reducing environment corrosion, as compared to the option of deep staging the entire lower furnace to a low stoichiometric firing condition.

Reburning is a sophisticated combustion modification technique that involves the control of many parameters including fuel and air flow rates, the ability to achieve good mixing of fuel and air, plus effective penetration of the overfire air stream (Figures 2 and 3). Reburing involves the staged addition of fuel into two combustion zones: the primary combustion zone (1) where three-quarters of the fuel is fired; and the reburn zone (2) where the remaining fuel is added to create a reducing condition to convert the NOx produced in the primary zone to molecular nitrogen (N2) and water. Flue gas recirculation (FGR) is added to the reburn burner windbox to improve mixing and furnace penetration. Combustion is completed in a burnout zone (3) in which OFA is added above the reburn zone. Stoichiometric ratios in each zone are unique as determined by the mass flow of fuel, burner air, and OFA.

Design approach

The proposed low NOx combustion system features sixteen main burners, eight reburn burners, and nine overfire air ports arranged in multiple levels as shown in Figures 2, 3 and 4. Babcock & Wilcox’s (B&W) computational fluid dynamic (CFD) program was used to assist in design optimization of the low NOx combustion system. Fluid flow, heat transfer, and combustion processes in the furnace were simulated using a collection of control volumes to represent the geometric feature of the actual Coleson Cove units.

The main burners are installed in the existing openings with eight burners on each of the front and rear walls. Similarly, eight reburn burners are installed above the upper top
level main burners with four burners on each of the front and rear walls. The main burners are designed to handle between 75 and 80% of total fuel input and operate with combustion air flow at near or equal to the theoretical air requirement.

The reburn burners are sized based on the remaining fuel input, plus the expected optimum FGR and air flows at substoichiometric levels. Nine OFA ports are installed in an interlace pattern with four ports on the front wall and five ports on the rear wall. The vertical distance between the main burners, reburn burners, and OFA ports are selected in accordance with B&W design standards to satisfy residence time requirements.

The remaining design tasks include selecting the optimal OFA port size, plus the horizontal spacing and configuration arrangement for both reburners and OFA ports. In addition, operating parameters and design features with respect to excess air, stoichiometric levels, FGR flow to reburn burners, burner and OFA port swirl patterns were determined based on the results of the CFD simulations. See Pham & MacLean (2006) for details of the combustion CFD modeling procedure and simulation results.

**NOₓ emissions performance** After successful commissioning of the three boilers in December 2004, a boiler optimization program was conducted jointly by NB Power and B&W to establish baseline operational and NOₓ emissions data. During the testing period, the plant burned Bunker C oil with the average fuel-bound nitrogen in the order of 0.45% by weight. The test was conducted from minimum (80 MWₑ) to maximum (350 MWₑ) continuous loads under various excess air and stoichiometry regimes. Figure 5 provides a summary of NOₓ emissions performance before and after retrofitting with the reburning system.

**Post-combustion NOₓ reduction**

Post-combustion NOₓ reduction using selective catalytic reactor (SCR) was considered during the project planning stage as a second option to achieve the NOₓ reduction goal of 0.21 lb/10⁶ Btu heat input. Although the SCR option was not implemented, the refurbished boilers incorporated provision for future installation of the SCR, if warranted.

**Post-combustion SO₂, SO₃ emissions reductions through WFGD and WESP**

NB Power’s approaches to SO₂ and SO₃ emissions reductions were: 1) to allow the use of Bunker C oil with high sulfur contents; 2) to employ limestone-based, forced oxidation flue gas desulphurization system for SO₂ reduction; 3) to reduce the visible SO₃ acid mists using WESP; and 4) to use the WESP as a secondary means of particulate capture.

The reduction of SO₂ and the elimination of SO₃ plume occur in an integrated WFGD and WESP system. The limestone-based, forced oxidation wet flue gas desulfurization scrubbing system is designed to remove 90% of SO₂, and the wet electrostatic precipitator to reduce the concentration of sulfuric acid mist to 5 ppm. The integrated system incorporates two absorber modules to process flue gas from three boiler Units 1, 2 and 3. Operational and maintenance flexibility is provided for by the combination of two absorber towers serving multiple boilers by arranging gas flues, dampers and plenums downstream of the ID fans enabling any boiler to feed either absorber.

Since the WFGD operates in an acidic environment, the absorber shell is constructed of corrosion resistant duplex Alloy 2205 material (UNS S32205). This is the first known commercial application of Alloy 2205 for FGD in North America. Another design feature includes the use of drum
filters for gypsum dewatering process which incorporate with heated water for final dewatering of the gypsum by-product to achieve 10% moisture (Figure 6).

A general system flow schematic of the WFGD process is depicted in Figure 7. The process begins with limestone reagent slurry preparation in which raw limestone in the silo is fed to a closed-circuit ball mill system producing a slurry of ground limestone and water. The feed slurry in the holding tank is pumped to the absorber reaction tank at a control flow rate to maintain the pH of slurry in the absorber reaction tank set point of 5.5. The slurry is pumped from the reaction tank to the spray headers located at the top of the absorber section. The pumps are among the largest sizes used for this application in North America. This slurry is sprayed counter current to the flue gas which enters at the lower section of the absorber. Oxidation air is added through the agitators to the lower section of the reaction tank to react with any sulfite present in the slurry to produce gypsum.

Spent slurry removed from the absorber typically contains about 15% suspended solids. A dewatering process first begins with a water separation in the hydroclones to concentrate the spent slurry to 25% solids. The second dewatering phase takes place in the rotary drum filters where the filtered solids are washed with heated water and further dried to form a gypsum cake containing less than 10% moisture.

The wet electrostatic precipitator is a three-field vertical up-flow design installed above the absorber tower (Figure 8). This extremely large, round WESP was a scale up from the small square WESP modules in use at the AES Deepwater plant in Texas. The Deepwater WESP is composed of 12 modules to service a 155 MW petcoke-fired boiler and has been in service since 1986. During the contracting phase, NB Power reviewed two options, a three-field unit capable of handling a FGD inlet loading of 50 ppm SO$_2$ and a slightly larger three-field unit capable of handling an inlet loading of 80 ppm SO$_2$. The larger unit was selected, as this became the first large up-flow WESP mounted integral on top of a WFGD.

The main function of the WESP is to control sulfuric acid aerosol below 5 ppmv at 3% O$_2$ and to limit solid particulate to less than 0.010 lb/10$^6$ Btu. To achieve this level of control on sulfuric acid at all times, the WESP collection efficiency is designed for greater than 90% efficiency. By definition, an aerosol can be considered as any particle having a diameter less than two or three micrometers, encompasses a low terminal velocity, not subject to normal gravitational force, and generally floats in the air for extended periods of time. The elimination of aerosols and acid mists takes place in three steps: particle charging, collection, and removal.

Flue gas enters the WESP after passing through the absorber outlet mist eliminators and flows upward through four parallel gas chambers. Each gas chamber is independently energized by high voltage bus section across each electrical field. This conservatively sectionalized, 12-bus section design allows for small sections to be de-energized during periodic water flushing, while maintaining overall emissions within design limits.

Each gas chamber is divided into several gas passages formed by collecting plates fabricated from corrosion resistant material. These collecting plates are made of C-276 for the inlet field and 6% Mo for the second and third fields. The 6% Mo material grade is a fully austenitic alloy, which contains a lower nickel and molybdenum content. This offers good corrosion resistance at a lesser cost than C-276. The material selection trade-off among C-276 and 6% Mo was made to balance between material costs and local corrosion potential.

Acid mist and particulate matter are charged by a corona current flowing from the high voltage discharge electrodes to the grounded collecting plates. The charged particles migrate to the collecting surface and are removed by a film of collected acid mist solution flowing down the collector plates augmented by periodic spray washing. Captured acid and particulate matter are collected by a gutter system and drained via external piping into the absorber reaction tank, where the acid is neutralized by the limestone slurry being used for the WFGD SO$_2$ removal cycle. This means that there is no additional cost for chemicals to neutralize the collected SO$_3$.

Cleaned flue gas then exits the top of the WESP module through a final outlet mist eliminator, which captures any re-entrained droplets that may be present during flushing cycles, and transitions directly into the stack through an outlet hood. This design simplifies and lowers the balance-of-plant costs that would be otherwise associated with a conventional arrangement where the WESP may be placed on a stand-alone basis and outside the wet FGD tower.

**SO$_2$ and SO$_3$ emissions reduction results** Comprehensive SO$_2$ and SO$_3$ emissions tests were conducted by NB Power on the two FGD towers in June 2005 for various operating load conditions. The WFGD and WESP performed exceptionally well achieving SO$_2$ emissions below 5 ppm and the SO$_2$ removal efficiency was 92.6% while burning a 1.84% sulfur oil during the acceptance test. This value matches the FGD SO$_2$ removal design efficiency of 90% when corrected for the design fuel with 3% sulphur content.
Plant efficiency improvements

NB Power’s secondary approach to reduce gas emissions is through optimized plant efficiency. This includes:

1. reduction of superheater and reheater sprays to improve steam turbine heat rate;
2. augmentation of steam turbine efficiency with modern turbine blading; and
3. reduction of internal plant power consumption by installing variable frequency drives (VFD) on the six new 4500 hp induced draft fans.

The boilers have historically been operated with large superheater and reheater sprays due to excessive furnace slugging. The refurbishment project provided an opportunity to alter the heat transfer pattern in the convection pass. This was accomplished by removing some primary superheater surface and by replacing a portion of the reheater heat transfer surface with economizer surfaces as shown in Figure 4.

Steam turbine efficiency was improved by replacement of the entire HP and IP inner casings and rotors. This renovation also included an upgrade to modern blade design for these components. Moreover, two rows of blades were added to the new HP stage for added efficiency. In addition, the latest 3-D high twist blade technology was fitted to the last stage (L-0) of the LP turbines, for additional efficiency enhancement.
Conclusion

The low NO\textsubscript{x} combustion system with reburning proved to be the optimal solution as compared to utilizing SCRs. This enabled NB Power to attain its emissions reduction objective with much less capital expenditure and shorter outage than would have been required if the SCR option had been selected. The integrated design WFGD and WESP achieved NB Power’s emissions reduction goals for SO\textsubscript{2} and SO\textsubscript{3} emissions while minimizing solid waste.

Incremental internal power consumption, plus emissions were inherently minimized via improvements to the overall plant efficiency through various initiatives, including upgrades to boilers and steam turbines.

The combination of sophisticated combustion technology, innovations in the post-combustion gas cleaning system and project improvements to reduce fuel consumption have enabled NB Power to successfully achieve its emissions reduction objectives for the Coleson Cove generating station.

References


